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Distance Limits for Traffic Noise Prediction Models

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Introduction

Caltrans noise analysts routinely use highway traffic noise prediction models to predict existing and future highway noise levels, with and without noise barriers, for adjacent receivers. Whenever possible, model results are compared to measurements and calibrated if necessary. The process of model calibration, described in the "Technical Noise Supplement to the Traffic Noise Analysis Protocol" (TeNS), is an important part of routine noise impact analysis and noise barrier design.

The model calibration process requires comparisons of model results with good quality noise measurements. Through more than two decades of these comparisons, noise analysts have gained a certain level of confidence in the prediction models. The prediction models currently in use by Caltrans (LeqV2, and Sound32/Sound2000) have generally shown satisfactory results for receivers within 200 feet (60 m) from a highway. Normally, most receivers of interest lie within this distance. Frequently, however, there is a need to extend the noise analysis beyond 200 feet (60 m) to include receivers that are more exposed to highway noise by virtue of the topography, or to determine the extent of highway noise impacts. There is a temptation for the noise analyst to exercise the model to distances beyond reasonable expectation of accuracy.

This Technical Advisory, Noise discusses setting the acceptable distance limit for current and future models.

Problems

Expressed in simple terms, traffic noise prediction models consist of two parts: 1) noise source strength and 2) propagation.

Source Strength - The noise source strength is calculated using reference energy mean emission levels (REMELS) for each vehicle type, the number of vehicles per hour and speed of each vehicle type, the speeds for each vehicle type, the number of roadways, and length of each roadway. These calculations are simple and if the REMEL database is accurate, the resulting equivalent noise level, referenced to a certain distance (usually 50 feet (15m)) is also accurate. Both LeqV2 and Sound32/Sound2000 perform adequately in the source strength portion of the models.

Propagation - Propagation is more difficult to model. Propagation of highway noise is governed by distance attenuation due to geometric spreading (the "spreading" of acoustical energy over ever-increasing areas away from the source), atmospheric absorption, ground absorption, reflections, shielding, and meteorological effects. LeqV2 and Sound32 both correctly account for the geometric spreading, and attempt to account for ground absorption with an alpha - factor, or site parameter, α. In addition, both models can account for shielding, such as barriers. The methodology on which the models are based is described in:

Barry, M. et al, "FHWA Highway Traffic Noise Prediction Model", FHWA-RD-77-108, FHWA, Washington, D.C., 1978.

Unlike LeqV2, Sound32/Sound2000 also deals with atmospheric (molecular) absorption in a simplistic manner. The method it uses and resulting differences between LeqV2 and Sound32/2000 are covered in detail the next section and the appendix.

Simple single reflections, such as noise reflecting off a noise barrier on the opposite side of a highway can be dealt with by creating image sources as described in the Technical Noise Supplement to the Caltrans Traffic Noise Analysis Protocol (TeNS).

The most recent FHWA Traffic Noise Model (TNM) uses more sophisticated algorithms for ground absorption and reflections, especially in the presence of noise barriers, and also has an atmospheric absorption algorithm.

None of the models have capabilities of dealing with varying meteorological conditions.

***Atmospheric Absorption Difference, LeqV2 and Sound32/Sound2000* –** Sound 32/Sound 2000 has a simple algorithm dealing with atmospheric (molecular) absorption. The algorithm is correct only for an air temperature of 68 degrees Fahrenheit (20 degrees Celsius), relative humidity of 50% to 70%, and a frequency of 500 Hertz. The algorithm is based on the simple equation:

$$A= -(5.4 * 10^{-4} * D) \qquad \textbf{(equation 1)}$$

Where: A is atmospheric absorption in dB, and D is source to receiver distance. The methodology is described in further detail in:

Bowlby, W. et al, "Noise Barrier Cost Reduction Procedure STAMINA 2.0/OPTIMA: Users Manual", FHWA-DP-58-1, FHWA, Washington, D.C., 1982.

LeqV2 does not incorporate any method for dealing with atmospheric absorption. Table 1 shows the differences between LeqV2 and Sound32/Sound 2000 due to atmospheric absorption, up to a distance of 2640 feet (1/2 mile). The table shows both the differences calculated from actual results of LeqV2 and Sound32/Sound 2000 and those calculated directly using the above equation 1. The method of calculating the former and the input assumptions are shown in the Appendix of this technical advisory.

Table 1 – Difference Due to Atmospheric Absorption

Source to Receiver Distance, ft (m)	Difference in Results, dB LeqV2 – Sound32/2000	Results from Equation 1, dB
200 (61)	0.0	-0.1
500 (152)	-0.1	-0.3
1000 (305)	-0.4	-0.5
2000 (610)	-0.9	-1.1
2640 (805)	-1.3	-1.4

Notice that the differences between the model results and the equation are no more than 0.2 dB and are presumably caused by differences in rounding off between LeqV2 and Sound32/Sound 2000. Comparison with the results of Equation 1 confirms the presence of the atmospheric absorption treatment in Sound32/Sound 2000 and the lack of the same in LeqV2. Differences between the two models become significant beyond 1000 feet (300 m).

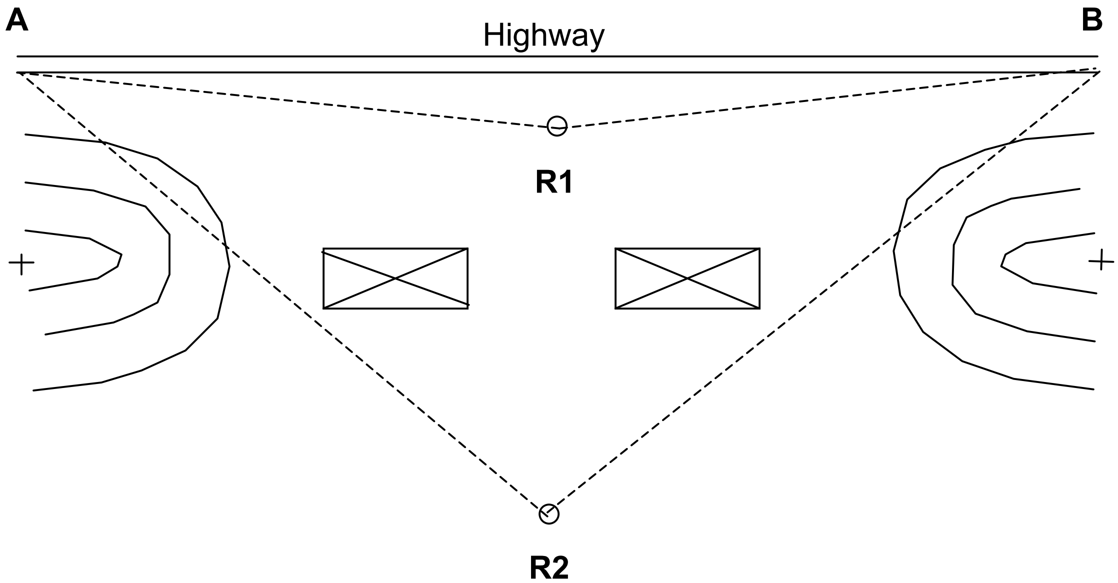
Increasing Distance, Increasing Complexity - As the distance between the highway traffic source and the receiver increases, the number and scale of variables affecting noise propagation increase substantially, as illustrated in Figure 1. To the receiver R1, the stretch of highway between A and B is for all practical purposes an infinite highway. For receiver R2, however, the highway becomes a finite highway, and the noise propagation path includes a greater geometric complexity. The current noise prediction models cannot satisfactorily account for partial shielding from buildings and low rises in terrain. Simplistic algorithms for dealing with excess attenuation due to ground absorption are a further concern.

Caltrans research has shown that even in flat, open, acoustically "soft" terrain the simplistic ground absorption algorithm causes Sound32/sound2000 to over-predict noise levels by an average of 4 dBA between 200 (60 m) and 500 feet (150 m) from the highway. The research was reported in:

> Hendriks, Rudolf W., "Traffic Noise Attenuation As A Function Of Ground And Vegetation (Final Report)", FHWA/CA/TL-95/23, California Department of Transportation, Engineering Service Center, Sacramento, CA, June 1995.

The over predictions were traced to the use of constant α – site parameter, which in reality proved to be varying with distance. The above research and other work were instrumental in demonstrating the need for developing a new, more sophisticated traffic noise prediction model resulting in FHWA TNM. TNM uses superior propagation algorithms. However, TNM results have not been sufficiently validated for distances greater than 500 feet (150 m).

Figure 1- Increasing highway - to - receiver distance increases the complexity of site geometry and reduces roadway segment from infinite to finite.



Predicted Vs. Measured Barrier Insertion Loss- Noise barriers are intended to protect receivers within several hundred feet from a highway. Within those distances they appear to be performing satisfactorily and as predicted. At greater distances, however, noise barriers are less effective. This has been confirmed through studies performed by URS-Greiner Woodward-Clyde and Illingworth & Rodkin, Inc. in the San Francisco Bay area in the 1990's, that showed that at distances of about 500 feet (50 m) or greater, barriers did not show significant noise reductions.

There are two reasons most frequently cited as the cause. First, the background noise, or community noise levels present without the highway noise, create a noise floor or minimum noise level. As distances from a highway increase, this noise floor is rapidly approached and noise barriers become ineffective. The second reason often cited is that of decreasing noise path length differences between no noise barrier and noise barrier. The diffraction theory per FHWA-RD-77-108 in LeqV2 and Sound32/Sound 2000 uses a Fresnel Number (N0), which is a function of the path length difference (PLD) between the direct (straight line) source-to-receiver noise path. When the PLD is expressed in feet, **N0 = 0.98 PLD**.

N0 can be positive when a noise barrier is higher than the line of sight between source and receiver, or it can be negative when the top of the barrier is below the line of sight. It can also be zero, when the line of sight grazes the barrier top. When it is zero, the barrier reduces noise levels by 5 dBA. When it is positive, the higher the N0 becomes, the greater the noise attenuation by the barrier will be, up to 20 dB maximum. When N0 is negative, the lower N0 becomes, the closer the noise attenuation approaches zero. The practical noise reduction for positive N0 from 0 to positive infinity is 5 to 20 dB, and for negative N0 from 0 to negative infinity from 5 to 0 dB. Close examination of some extreme cases show that PLD, and therefore N0 can increase, decrease, or stay about the same with distance, depending on the site geometry and barrier height. This is illustrated in three examples shown in Figures 2a, b, and c.

Figure 2a shows the PLD, N0, and Attenuation for a 14-foot high noise barrier for autos only, on a level site with two 5-foot (1.5 m) high receivers R1 and R2, at 100 feet (30 m) and 1000 feet (300 m) respectively from the roadway. The barrier is located 50 feet (15 m) from the roadway. A is the noise source (autos), B is the top of noise barrier. The PLD's for R1 and R2 are defined as AB + BR1 – AR1, and AB + BR2 – AR2, respectively. In this case, the PLD and N0 decrease with distance. At 100 feet (30 m) the barrier attenuation predicted for autos is –13.0 dB. At 1000 feet (300 m) the predicted attenuation is –12.1 dB.

Figure 2a – PLD, N0, and Attenuation for 14' high Noise Barrier, at 100' and 1000' Autos only

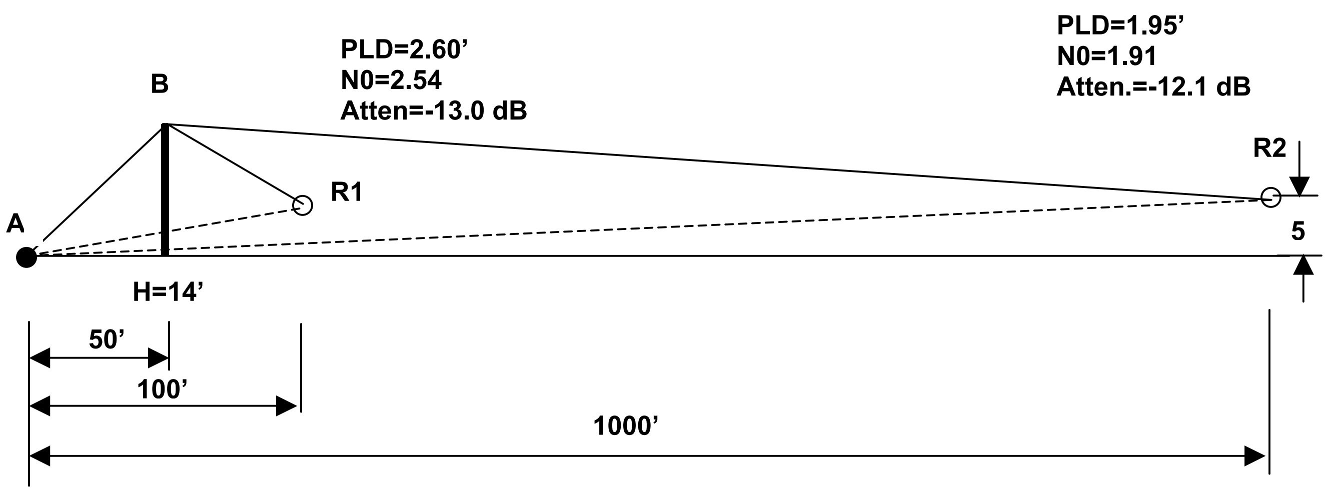


Figure 2b shows the same situation as in Figure 2a, except that the barrier is 6 feet high. Note that in this example, the PLD and N0 increase slightly with distance. The attenuation predicted for 100 feet (30 m) is –7.1 and at 1000 feet (300 m) it is –7.7 dB, or slightly larger. The only difference between Figure 2a and Figure 2b is the barrier height. Yet in Figure 2a the PLD and N0 decreases somewhat with distance, and in Figure 2b the reverse is observed.

Figure 2c depicts the same situation as in Figure 2a, except that heavy trucks (HT) are added in. The ratio of HT and autos is important in predicting the barrier attenuation. In this case a ratio of 13 autos to 1 HT (i.e. 92.9% autos and 7.1% HT) was used to calculate the combined attenuation. Note that for this typical situation the barrier attenuation decreases by less than 2 dB from –11.7 at 100 feet (30 m) to –9.8 dB at 1000 feet (300 m).

Figure 2b – PLD, N0, and Attenuation for 6' high Noise Barrier, at 100' and 1000' Autos only

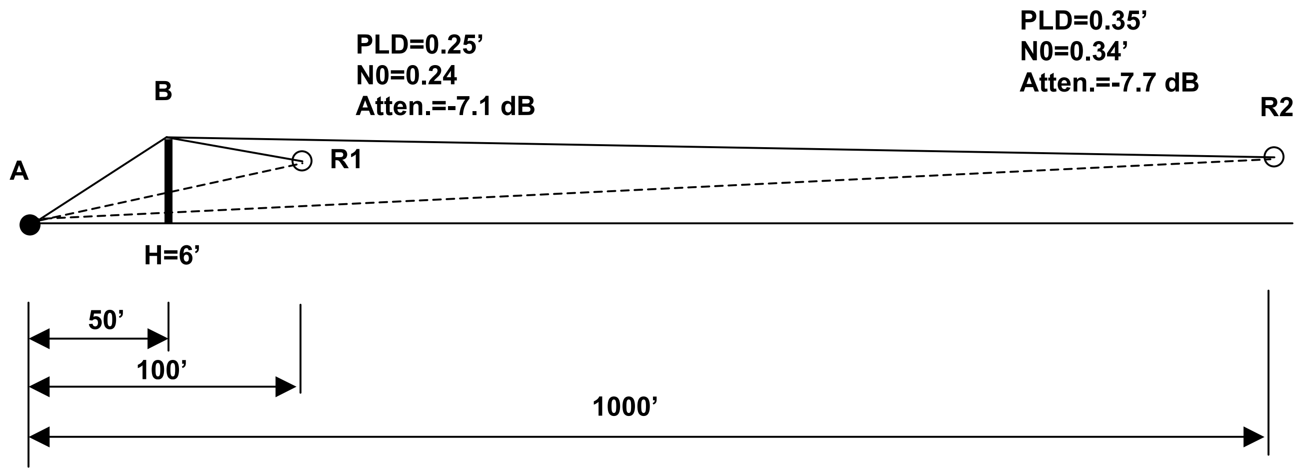
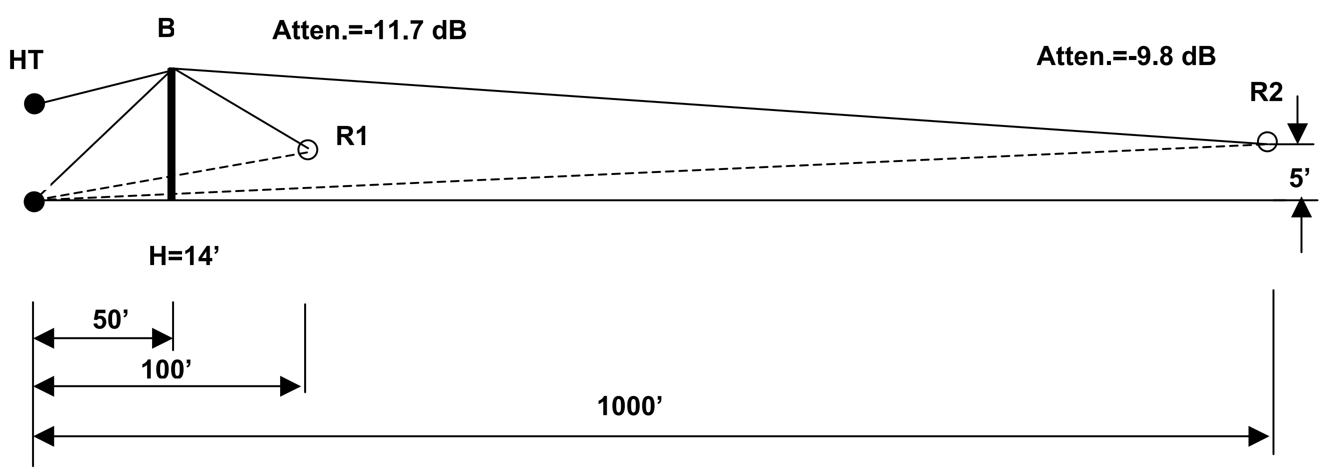


Figure 2c – Barrier Attenuation for 14' high Noise Barrier, at 100' and 1000' for 92.1% Autos and 7.1% Heavy Truck mix



Figures 2a, b, and c are shown for flat terrain. The PLD and N0 can of course vary far greater in undulating terrain, receivers on hill sites, depressed freeways and highways on embankments.

The high barrier attenuations predicted for 1000 feet (300 m) on level terrain are misleading as to the effectiveness of noise barriers at those distances. First, attenuations have not been verified at distances greater than 500 feet (150 m) in current models. Second, as mentioned earlier, background noise levels are extremely important, especially at distant receivers and need to be added into the noise predictions. The principal reason that noise barriers are not as effective in the real world at long distances is not necessarily that barrier attenuation decreases significantly, but more likely that the noise levels without a noise barrier are already low at those distances. A barrier cannot reduce noise levels below the background noise. Whatever the reasons may be for a given situation, noise barriers are not as effective at distances over 500 feet (150 m) as current prediction models may lead the analyst to believe.

Meteorology - None of the current prediction models, including TNM have any provisions for dealing with the effects of meteorology. With increasing distances, meteorological conditions have an increasing effect on noise levels, due to atmospheric refraction. The most significant meteorological parameters are wind speed and direction, and temperature gradients with height above ground (i.e. temperature inversions and lapse conditions). Wind can have a significant effect at 200 feet (60 m) to 400 feet (120 m), and the effects of temperature gradients can be dominant at greater distances. The current prediction models by default are accurate only for neutral atmospheric conditions, i.e. no wind and no temperature gradients. Large differences between noise predictions and measurements can and will exist at distances over 500 feet (150 m) due to varying meteorological conditions. Meteorological effects on noise levels are described in greater detail in TeNS.

Recommendations

For reasons of the uncertainties in the current prediction models, the over predictions at 200 to 500 feet (60 to 150 m) uncovered in previously mentioned Caltrans research, and propagation algorithms inadequate to deal with long distance noise prediction, the author recommends that the use of LeqV2 and Sound32/Sound 2000 generally be limited to a distance of 500 feet (150 m). That is not to say that a sensitive receiver lying at for instance 523 feet from the highway should definitely be excluded, and a receiver at 496 feet definitely be included. Judgment should be used in all cases. The more complex the intervening terrain becomes, the more rigid the 500-foot limit should be applied, and in some extreme complex cases the 500-foot limit might prudently be reduced.

The 500-foot (150 m) limit is also recommended for future models, including TNM. The limit should only be extended after these models have been adequately validated for greater distances. Any attempt to validate future models for distances beyond 500 feet should be done in accordance with technical advisory TAN-98-01-R9701, titled: “General Guidelines For Studying

The Effects Of Noise Barriers On Distant Receivers", prepared by this author, November 30, 1998.

APPENDIX
Calculation Of Differences Between LeqV2 and Sound32/Sound 2000 Due To Atmospheric Absorption

ATMOSPHERIC ABSORPTION FOR SOUND32

Given: One lane 40,000 feet (almost 8 miles) tangent.	
Traffic (VPH)	A=895 MT=35 HT=70 Spd=55mph
Receivers:	R200@200' R500@500' R1000@1000' R2000@2000' R2640@2640' (1/2 mile)
Dropoff Rate:	3 dBA/DD

LeqV2 Infinite Roadway inputs: see above, all receivers used -90deg to +90deg roadway segments.
Dropoff Rate see above

LeqV2 Finite Roadway inputs, see above with following roadway segments (corresponding to S32 inputs):	
Roadway Segments for Receivers:	R200: -89.4 to +89.4 deg R500: -88.6 to +89.6 deg R1000: -87.1 to +87.1 deg R2000: -84.3 to +84.3 deg R2640: -82.5 to +82.5 deg
Dropoff Rate:	3 dB/DD

Sound32 inputs: Traffic Inputs see above				
Lane:	Gr. Adj.:N	x=-20000	y=0	z=0
	Gr. Adj.:N	x=20000	y=0	z=0
Receivers:	R200	x=0	y=200	z=5
	R500	x=0	y=500	z=5
	R1000	x=0	y=1000	z=5
	R2000	x=0	y=2000	z=5
	R2640	x=0	y=2640	z=5
Dropoff Rate:	3 dB/DD			

Comparison of Results:

Receiver Dist. (D), ft	Dropoff Ref: 200' 10log(200/D)	LeqV2 Inf. Res.	Difference (Inf-Dropoff)	LeqV2 Fin. Res.	Sound32 Fin. Res.	Atmospheric Absorption LEQV2- S32
200	0.0	66.9	0.0	66.9	66.9	**0.0**
500	-4.0	62.9	-0.0	62.8	62.7	**-0.1**
1000	-7.0	59.9	-0.0	59.8	59.4	**-0.4**
2000	-10.0	56.9	0.0	56.6	55.7	**-0.9**
2640	-11.2	55.7	0.0	55.3	54.0	**-1.3**

COMPARISON WITH EQUATION 1 (Eq. A-16 PAGE A-8 IN FHWA-DP-58-1): A= -(5.4*10^-4*D)

Receiver Distance, ft	Atmosph. Absorption LEQV2- S32	Atmosph. Absorption Equation 1	(T=68 deg F; R.H.= 50-70%)
200	**0.0**	**-0.1**	
500	**-0.1**	**-0.3**	
1000	**-0.4**	**-0.5**	
2000	**-0.9**	**-1.1**	
2640	**-1.3**	**-1.4**	